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Research Article

A Model for Dynamic Routing of Multiuser Communication Network

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Abstract:
In this paper a dynamic model for competitive routing in multi user communication network is presented. Dynamics has been introduced by considering the status of the communication network over a period of time, time dependence of link capacity and availability, and accordingly the cost function. We use game theoretical concepts to analyze this model. We assume that each user of the communication network can control the amount of flow to optimize his gain (or to minimize cost).

Keywords: dynamic model, symmetrical link, communication network.

I. INTRODUCTION

Routing in a communication network is a game with imperfect information where the complete knowledge of strategies of other players is impossible. In this game decisions are made simultaneously by all the users and cost functions are known to every player.

There are some works done in this field to show the routing models in a communication network. In [1], the authors A. Orda, R. Rom and N. Shimkin provide nash equilibrium for the system of two node multiple link using non-cooperative game. They have proved uniqueness of NEP under reasonable convexity conditions.

I. Sahin, M.A. Simaan [2] derived an optimal flow and routing control policy for two node parallel link communication networks with multiple competing users. The review paper by F.N. Pavlidou and G. Koltsidas [3] presents different routing models that use game theoretical methodologies for conventional and wireless networks as well.

Time dependent behavior has an impact on the performance of telecommunication models and queuing theory is also implemented for communication perspective by Messey [4].

This work presented here deals with routing of data packets in a communication network. We analyze the cost function for this routing problem. Consider that transmission time of packets has great impact on this cost function. The rest of the paper comprises four sections. In section 2, we present a mathematical modeling for communication network, which includes some assumptions and constraints. In section 3, Routing Scheme will be discussed which shows the relation of cost function with time and number of packets. In section 4.1 and 4.2, we illustrate combined routing by symmetrical users in symmetrical and non-symmetrical links. In section 5, we present a game of routing, and section 6 we provide some concluding remarks.

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II. MATHEMATICAL MODELING

In communication network model we consider n users shared l parallel links connecting a common source node to a common destination node. Let $L = \{1, 2, 3, \ldots . l\}$ be the set of parallel links and $N = \{1, 2, 3, \ldots \ldots n\}$ be the set of users. We assume that users are rational and selfish for this competitive game. Each user $n \in N$ has throughput demand D^n which he wants to ship from source to destination. A user sends his throughput demand in the form of data packets through the communication links. A user is able to decide at any time how the data packets will be transmitted and what fraction of throughput demand should be sent at that time through each link. We assume that each link is available for all the users after a unique interval of time. Capacity λ_l of each link is fixed. Let i packets are transmitted on l link at time t by user n is denoted by $P^n_{(i,l)}(t)$.

$P^n_{(i,l)}(t)$ satisfies the following conditions :

P$_1$: $\quad P^n_{(i,l)}(t) \geq 0$

(Non – negative constraint)

P$_2$: $\quad \sum_n \sum_i P^n_{(i,l)}(t) \leq \lambda_l$

(Capacity constraint for each link l)

P$_3$: $\quad D^n = \int_0^T \sum_n \sum_i P^n_{(i,l)}(t)\, dt$

(Demand constraint for each user n)

Turning our attention to a link $l \in L$, let $P_l(t)$ be the total transmitted packets on that link at time t and s_l be the speed of data packets for link l, which is fixed for $l \in L$. We visualize this problem as a non-cooperative game in which each user wants to minimize its cost C^n, since the cost function depends on the no. of packets routed and time t for the user n, it turns out that the optimal decision of each user depends on the proper use of link capacity within first few time intervals.

The following general assumptions on the cost function C^n of each user $n \in N$ imposed throughout the paper.

A$_1$: $\quad C^n = \sum_i \sum_l C(P^n_{(i,l)}, t)$

It is a sum of cost of routed packets over each link $l \in L$ by user $n \in N$.

A$_2$: Cost function is non- linear and positive function .

A$_3$: Cost function is strictly increasing with no. of packets i and time t.

Cost of a packet $\quad C_{p_i} = f(t)\,.\,\emptyset(i)$

We assume that distance between source to destination node can be covered within T time by the packets.(for simplicity let T=1sec. and distance between source to destination be 1 unit)

Additional assumptions concerning the time function $f(t)$ are

T$_1$: Time T can be subdivided into small intervals.

T$_2$: Interval size depends on the transmission rate for a user to the link l. Since the transmission rate is fixed for a link therefore interval size is also fixed for that link.

T$_3$: Flow of packets is continuous which implies that there is no congestion in the system.

T$_4$: Users can transmit their packet on the link at the same time interval. They must obey the capacity constraint (P$_2$) and non-negative constraint (P$_1$).

III. ROUTING SCHEME

We analyze routing scheme in a single link dynamic system for a user. The user can route one or more packets on this link at time t. (fig. 3.1)

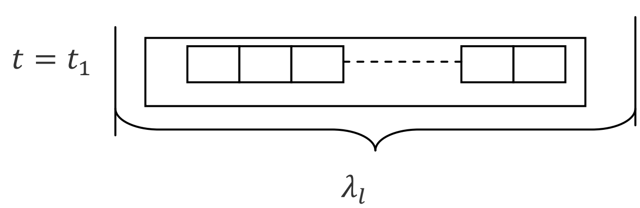

Fig 1: Available space at $t = t_1$

The expected cost C for the user n depends on the no. of packets i to be routed and time slots t.

$$C^n = f(t).\phi(i)$$

Where $f(t) = \big(1 + int(t)\big).(1 + t)$

$$\phi(i) = \begin{cases} \frac{e^i}{\lambda_l + 1 - i} & when\ i \le \lambda_l \\ \infty & when\ i > \lambda_l \end{cases}$$

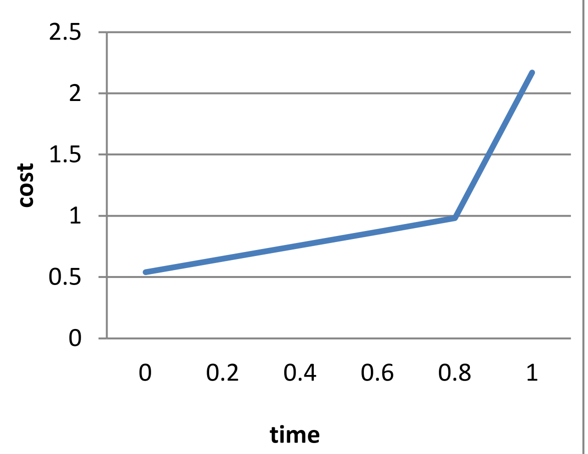

Fig 2: Cost of One Packet in Different Time Slots

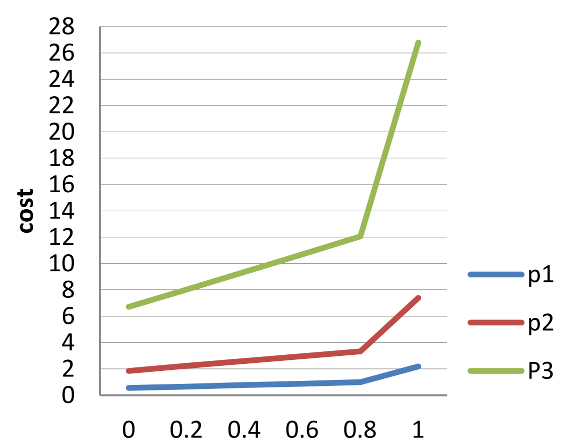

Fig 3: Cost of Pn packets in Different Time Slots

The time function $f(t)$ is a product of two expressions in which first expression $(1 + int(t))$ gives the cycle number in which data to be transmitted.

IV.1 COMBINED ROUTING BY SYMMETRICAL USER IN SYMMETRICAL LINK

Consider two node parallel link network with two users. Suppose that both users have the same demands (i.e. no. of packets to be transmitted) and same source and destination nodes. Also both user use the same cost function. i.e for all $n, m \in N$, $P^n = P^m$ and $l_1, l_2 \in L$ use the same cost function, they still have different value because it depends on no. of packets i or j transmitted and time t (Assumption A$_3$).

$$C^n = \sum_i \{C(P^n_{(i,l_1)}, t) + C(P^n_{(i,l_2)}, t)\}$$

$$C^m = \sum_j \{C(P^m_{(j,l_1)}, t) + C(P^m_{(j,l_2)}, t)\}$$

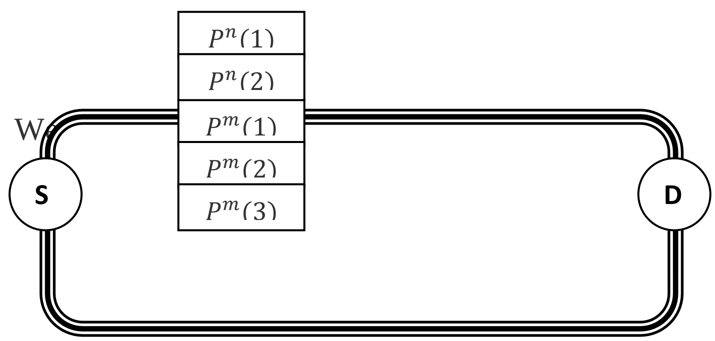

Fig. 4: Combined transmission by symmetrical user m and n

Example: We present an example to illustrate the cost function for combined routing in symmetrical link by symmetrical user.

Let the capacity of links be $\lambda_1 = \lambda_2 = 5$, and demand of user 1 and 2 be 10 packets each.

Table I: Illustration of different values of cost function for different no. of packets.

	First Cycle					
No. of packets	t=0	t=0.2	t=0.4	t=0.6	t=0.8	t=1.0
1	0.54	0.65	0.76	0.87	0.98	2.17
2	1.85	2.22	2.59	2.96	3.33	7.39
3	6.70	8.03	9.37	10.71	12.05	26.78
4	27.30	32.76	38.22	43.68	49.14	109.20
5	148.41	178.10	207.78	237.46	267.14	593.65

Each user can transmit their data packets using T_4 such that cost of 10 packets will be minimum.

IV.2 COMBINED ROUTING BY SYMMETRICAL USERS IN NON-SYMMETRICAL LINK

Again, we start with two node parallel link network with two users. Suppose that both user have same demands, same source and destination, but links are not symmetrical i.e. speed of packet transmission through both links are different. We can explain the situation of combined routing in such a network by following example.

Example: Let the capacity of links be $\lambda_1 = \lambda_2 = 5$, and demand of user 1 and 2 be 10 packets each and speed of first link l_1 is s and second link l_2 is $2s$. i.e. second link l_2 is faster than $l_1$or link l_2 is frequently available to transmit user's data than l_1.

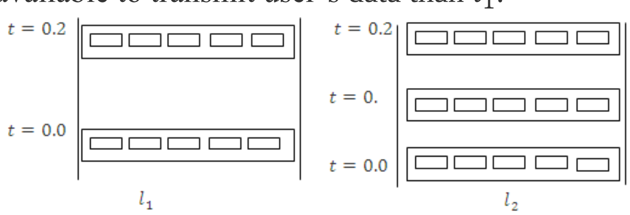

Fig 5: Comparison of available slots on l_1 and l_2

Also since l_2 is faster than l_1 cost for packets through l_2 is more than l_1.

Cost function for link l_1 to route i packets is

$$C = f(t).\phi(i)$$

Where $f(t) = \big(1 + int(t)\big).(1 + t)$

$$\phi(i) = \begin{cases} \frac{s.e^i}{\lambda_l + 1 - i} & when\ i \le \lambda_l \\ \infty & when\ i > \lambda_l \end{cases}$$

Cost function for link l_2 to route i packets is

$$C' = f(t).\phi'(i)$$

Where $f(t) = \big(1 + int(t)\big).(1 + t)$

$$\phi(i) = \begin{cases} \dfrac{2s.e^i}{\lambda_l + 1 - i} & when\ i \le \lambda_l \\ \infty & when\ i > \lambda_l \end{cases}$$

[where s is speed of transmission, let $s = 1\ unit/sec.$]

Table II: Illustration different value of cost function for different no. of data packets in different time slot on link l_2.

	First Cycle					
No. of packets	t=0	t=0.1	t=0.2	t=0.3	t=0.4	t=0.5
1	1.09	1.20	1.30	1.41	1.52	1.63
2	3.69	4.06	4.43	4.80	5.17	5.54
3	13.39	14.73	16.07	17.41	18.75	20.09
4	54.60	60.06	65.52	70.98	76.44	81.90
5	296.83	326.51	356.19	385.87	415.56	445.24

V. GAME OF ROUTING

In order to illustrate the game of routing consider the same network with same parameter explained in section 4.2.

We assume that the users are capable of sending data packets on both available link whose maximum available capacities are $\lambda_1 = \lambda_2 = 5$ at time t. Both user wants to minimize its cost .

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Table III: Data transmitted by both user through link l_1 and l_2 at different time slots and its cost.

Game-1		t=0	t=0.1	t=0.2		
u1	l1(high Speed)	3	2	2		
	l2	2		1		
u2	l1(high Speed)	2	3	2		
	l2	3				total
Cost(u1)		20.56	5.26	6.388		32.21
Cost(u2)		13.87	19.99	5.738		39.60

From above example we conclude that if any user uses faster link at the initial time slots in the session, it will be optimal value for that user. If user prefer faster link later on cost will be increased exponentially which is not feasible for user.

VI. CONCLUSIONS

In this work, we attempted to present mathematical modeling in communication network. In particular, using the conventional networks (i.e. two nodes parallel links with two user), we continued with dynamic routing. The cost function is characterized by no. of packets to be routed and time variable, in a non-linear fashion. Speed constants are also introduced for non-symmetrical link which affect the cost function for that link. Each user is given the flexibility of choosing link to route their data at different time slots. The examples also demonstrate the cost function depends upon packets and time interval.

Despite the results accomplished so far, there is space for more detailed investigation for multiuser, complex network with non-symmetrical link. Furthermore, different demands and different source and destination seem to play a critical role in this packet transmission that has not been investigated in detail yet.

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